Journal of Athletic Training 2002;37(4):436–445

www.journalofathletictraining.org

Biomechanical and Neuromuscular Effects of Ankle Taping and Bracing

Gary B. Wilkerson

The University of Tennessee at Chattanooga, Chattanooga, TN

Gary B. Wilkerson, EdD, ATC, provided conception and design; analysis and interpretation of the data; and drafting, critical revision, and final approval of the article.

Address correspondence to Gary B. Wilkerson, EdD, ATC, The University of Tennessee at Chattanooga, Graduate Athletic Training Program, Department 6606, 615 McCallie Avenue, Chattanooga, TN 37403-2598. Address e-mail to Gary-Wilkerson@utc.edu.

Objective: An extensive review of clinically relevant research is provided to assist clinicians in understanding the underlying mechanisms by which various ankle-support systems may provide beneficial effects. Strategies for management of different types of ankle ligament conditions are also discussed.

Background: Much of the literature pertaining to ankle instability and external support has focused on assessment of inward displacement of the hindfoot within the frontal plane. Some researchers have emphasized the importance of (1) pathologic rotary displacement of the talus within the transverse plane, (2) the frequent presence of subtalar joint ligament lesions, and (3) the interrelated effects of ankle support on deceleration of inversion velocity and facilitation of neuromuscular response.

Description: The traditional method for application of adhesive tape to the ankle primarily restricts inward displacement of the hindfoot within the frontal plane. The biomechanical rationale for a method of ankle taping that restricts lower leg rotation and triplanar displacement of the foot associated with subtalar motion is presented.

Clinical Advantages: The lateral subtalar-sling taping procedure may limit strain on the anterior talofibular ligament associated with subtalar inversion, restrain anterolateral rotary subluxation of the talus in the presence of ligament laxity, and protect the subtalar ligaments from excessive loading. The medial subtalar sling may reduce strain on the anterior-inferior tibiofibular syndesmosis and enhance hindfoot-to-forefoot force transfer during the push-off phase of the gait cycle.

Key Words: ankle instability, subtalar joint injury, ankle dysfunction

For more than a century, ankle taping has been advocated as a means to protect the ankle ligaments from excessive strain.[1] Widespread belief in the effectiveness of ankle taping and the extremely high incidence of lateral ankle sprains among athletes resulted in ubiquitous use of the procedure within scholastic and professional athletic organizations for many years. The skillful application of adhesive tape to the ankles of athletes remains strongly associated with the role of the athletic trainer today. One prospective study[2] has documented the effectiveness of ankle taping in reducing sprain incidence, and numerous researchers have evaluated the extent to which tape provides a mechanical restraint to excessive ankle motion.[3–21] Literature on the subject also contains descriptions of various tape-application procedures for the ankle[22–31] and critical analyses of the benefits that may be derived from ankle taping.[32–38] Some researchers have emphasized that ankle taping rapidly loses its initial level of resistance to motion during exercise,[11,12,14,17] but most studies on the mechanical effect of taping have demonstrated some level of motion restriction after exercise. Although tape clearly loosens significantly during exercise, its restraining effect on extreme ankle motion is not eliminated by prolonged athletic activity.[3,6,9,10,15,19–21]

In recent years, a variety of ankle braces have become commercially available as alternatives to ankle taping. Some investigators have studied the mechanical effect of various brace designs on restraint of ankle motion,[39–47] and many such studies have compared the mechanical effects of bracing and taping.[47–59] Some researchers have found comparable levels of postexercise motion restraint for taping and bracing,[49,51,52,54,56,59] whereas others have concluded that ankle bracing is superior to taping on the basis of less exercise-induced increase in ankle motion with bracing.[50,53,55,57] In a recent meta-analysis of 19 studies of the effects of different types of ankle support on ankle motion before and after activity, significantly greater frontal-plane ankle-motion restriction after exercise was found for a semirigid stirrup brace design than for taping or a lace-up type brace.[60] Several prospective studies have documented a beneficial effect of semirigid ankle bracing on sprain incidence,[61–63] and 2 retrospective studies comparing the effects of taping and a lace-up brace on sprain incidence supported the superiority of bracing for injury prevention.[64,65] Despite these findings, some sports medicine clinicians and athletes believe that taping provides superior benefits related to comfort, perception of greater support, and less interference with normal ankle function.

EFFECTS ON PERFORMANCE CAPABILITIES

A number of authors have evaluated the effects of ankle taping and bracing on the functional performance capabilities of normal and injured subjects.[50,56,66–84] Findings regarding the extent to which ankle support may interfere with normal function have been inconsistent, and no clear conclusions can be drawn concerning the relative effects of different brace designs (eg, semirigid versus lace up). For example, some researchers found that various forms of ankle support decreased vertical jump height by 3% to 5%,[56,69,77,82,83] whereas others did not observe a significant effect.[50,68,74–76,80,81,84,85] Some investigators observed significantly decreased performance on multidirectional agility tests for uninjured subjects wearing ankle support,[56,69] whereas others did not find a difference between supported and unsupported conditions.[67,68,75,80,81,83,85] Most of the studies comparing the effects of taping and bracing on performance have not demonstrated significant differences between taping and various types of braces.[50,56,67,79,83,85] One group of researchers has suggested that stirrup-type braces are superior to taping and lace-up braces on the basis of a less adverse effect on sagittal-plane isokinetic strength and range of motion.[73]

Surprisingly, relatively few authors have evaluated the extent to which ankle support may improve the functional capabilities of subjects with ankle dysfunction.[72,74,76] None have evaluated different ankle-taping methods or different brace designs, as all 3 of the cited studies evaluated the effect of the same semirigid, stirrup-type brace. Gross et al[74] found no significant beneficial effect on agility test performance for subjects with a history of recurrent ankle sprains, whereas Hals et al[76] reported significantly improved agility test performance for subjects with a postacute sprain when wearing the brace. Fridén et al[72] observed significant improvement in unilateral postural balance in subjects with a postacute sprain wearing the stirrup-type brace.

Although research evidence supports protected functional use as the most appropriate management of an acute lateral ankle sprain of any degree of severity,[86–88] relatively little scientific information pertains to the influence of ankle-support characteristics on recovery of optimal ankle function. Athletic trainers have long used the open-basketweave ankle-taping procedure to restrict ankle motion and control edema,[22,24,25,29,31] and stirrup-type ankle braces have been designed to provide the same therapeutic benefits.[89,90] Two studies of the effects of different brace designs on edema control and the rate of restoration of functional capabilities produced conflicting results.[91,92] A potentially important area of research that has not been thoroughly investigated is the relationship between specific structural characteristics of various ankle supports and their suitability for achieving different beneficial effects, such as restricting frontal-plane motion and transverse-plane motion, reducing ankle-displacement velocity, controlling edema, reducing load on specific ligaments, and enhancing proprioceptively mediated joint stabilization.

ALTERNATIVE MECHANISMS OF BENEFICIAL EFFECT

A number of investigators have provided information about alternative mechanisms by which ankle support may offer protection during a potentially injurious event. The effects of ankle taping and bracing on proprioceptive input to the central nervous system,[71,93–95] peroneal muscle activity,[3,6,10,96,97] and deceleration of ankle motion[6,15,18,47] may be as important as restriction of the range of ankle inversion for sprain prevention.

Feuerbach and Grabiner[71] found that both anteroposterior and mediolateral postural sway were decreased in normal subjects when a semirigid, stirrup-type brace was worn. The possibility that the improvement was due to enhanced proprioceptive input to the central nervous system was evaluated in a subsequent study of the effect of the brace on joint position sense, both with and without ankle-joint anesthesia.[93] Because the presence of the brace improved the accuracy of active replication of reference ankle positions in each of 3 planes, even in the anesthetized condition, the authors concluded that the stirrup-type brace enhanced proprioception from cutaneous mechanoreceptors.

Simoneau et al[95] found that tape straps adhered to the skin significantly improved joint position sense in nonweight-bearing plantar flexion. Heit et al[94] noted that taping and a lace-up brace both significantly improved the ability of subjects to actively reproduce a specific plantar-flexion joint angle. Because taping also significantly enhanced inversion position sense, they suggested that taping may be more effective than bracing for improving ankle joint proprioception. Awareness of ankle-joint position is clearly most important immediately before ground contact in order to avoid landing in an inverted position, whereas peroneal muscle activation is essential to counteract a potentially injurious force after landing.

Glick et al[96] were the first to present evidence of a relationship between peroneal muscle activity and the presence of tape on the ankle. Using electromyography (EMG) and cinematography, they found that the peroneus brevis muscle was active for a longer period of time at the end of the swing phase, just before footstrike, when the ankle was taped. Spriggings et al[97] also used EMG to assess the effect of taping on peroneal activation, expecting that the tape would relieve strain on the lateral anatomical structures of the ankle and decrease evertor muscle activation during a step-down maneuver and a simulated weight-bearing inversion-sprain motion. Contrary to this expectation, which was derived from the concern that long-term taping might ultimately produce peroneal weakness, taping did not prevent the evertor musculature from being vigorously activated.

Karlsson and Andréasson[6] used EMG to assess the effect of taping on the speed of peroneal response to sudden weight-bearing inversion in subjects with normal and mechanically unstable ankles. Tape on mechanically unstable ankles decreased the response latency of both the peroneus brevis and peroneus longus muscles by 8% (75.2 versus 81.6 milliseconds) and 13% (73.4 versus 84.5 milliseconds), respectively; the greatest improvement in response speed was in ankles with the greatest degree of instability.

Lohrer et al[10] analyzed the effects of taping on both peroneal EMG activity and restraint of weight-bearing lateral ankle displacement. They concluded that reduction in the angular velocity of displacement with tape, combined with restricted displacement amplitude, permitted relatively greater peroneal activation per degree of motion than the untaped condition. The ‘‘proprioceptive amplification ratio,’’ calculated as the integrated peroneal EMG activity divided by the maximum inversion amplitude, was presented as a means of quantifying the interrelated neuromuscular stimulation and motion-restriction effects of taping. Further evidence supporting this concept was presented by Alt et al,[3] who used identical methods to evaluate the effects of ankle taping before and after 30 minutes of exercise. Compared with the untaped condition, ankle taping reduced the postexercise inversion amplitude by 38% and the postexercise integrated EMG activity by only 20%. Thus, taping produced relatively greater integrated peroneal EMG activity within the restricted range of inversion than that observed for the corresponding portion of the range of unrestricted inversion.

Vaes et al[47] used radiographic cinematography to assess the effect of ankle bracing on inversion velocity during a weight-bearing sprain simulation that induced 50° of inversion displacement. A stirrup-type brace decreased the distance that stable and mechanically unstable ankles were displaced during a 40-millisecond high-velocity phase of the sprain simulation by approximately 15% to 20%. Approximately 40% of the 50°-inversion displacement of the unbraced ankles occurred during this high-velocity phase, which occurred within the 40- and 80-millisecond intervals after inversion displacement began. Conversion of their reported ankle-displacement data from pixels to degrees of motion yields an estimated velocity of approximately $400°\cdot s^{-1}$ to $450°\cdot s^{-1}$ for the unbraced ankles, which is consistent with the $400°\cdot s^{-1}$ injury velocity estimate of Alt et al[3] and the maximum inversion velocity value of $460°\cdot s^{-1}$ reported by Pederson et al[15] for untaped ankles.

Ricard et al[18] reported a maximum inversion velocity of $740°\cdot s^{-1}$ for untaped ankles and a corresponding average inversion velocity of about $370°\cdot s^{-1}$ for a 37° range of displacement. Taping decreased both the maximum and average postexercise inversion velocities by 31% to velocities of $511°\cdot s^{-1}$ and $254°\cdot s^{-1}$, respectively. Clarke et al[98] and DeClerq[70] reported almost identical maximum velocity values of $532°\cdot s^{-1}$ and $533°\cdot s^{-1}$ for subtalar eversion during running. Although the values for inversion velocity derived from trapdoor platforms are relatively similar to those observed for subtalar eversion during running, the velocity of ankle displacement associated with jump landing may exceed $1000°\cdot s^{-1}$. Ricard et al[99] suggested that most ankle injuries occur between 30 and 50 milliseconds after ground contact. Vaes et al[47] demonstrated that 50° of weight-bearing inversion displacement did not produce harm or discomfort, which suggests that some greater amount of displacement is necessary for lateral ankle-ligament injury. Thus, inversion velocity must be greater than $1000°\cdot s^{-1}$ to produce ankle displacement beyond 50° in less than 50 milliseconds.

Konradsen et al[100] and Alt et al[3] reported a 50- to 65-millisecond delay between the initiation of sudden inversion and the onset of peroneal EMG activity and a total time of at least 120 milliseconds required for generation of an effective muscle force to resist the inversion displacement. The findings of Glick et al[96] concerning the faciliatory effect of tape on peroneal activation before footstrike and those of Karlsson and Andréasson[6] concerning the faciliatory effect of taping on the speed of peroneal response to sudden weight-bearing inversion suggest that the peroneal muscles may generate an effective restraining force against inversion displacement in less than 120 milliseconds when the ankle is taped.

Assuming that the peroneal muscles are completely relaxed at the start of inversion, a velocity of approximately $300°\cdot s^{-1}$ or less would allow for generation of a resisting eversion force before the ankle is displaced beyond 40° of inversion. Ricard et al[18] reported that the postexercise average inversion velocity for taped ankles was approximately $250°\cdot s^{-1}$. They also presented evidence that high-velocity weight-bearing inversion demonstrated smaller amounts of postexercise support loss in taped ankles than very low-velocity open-chain inversion. This suggests that both the deceleration and motion-restriction effects of taping are rate dependent and are relatively more effective at high velocities of ankle displacement.

The contradictory findings of past research on the relative effects of ankle taping and bracing may be explained by variations in tape-application procedures, variations in the properties of tape and other materials used in the application process, methodologic limitations imposed by the risk of injury to subjects, and the exceedingly complex nature of the integrated biomechanical function of the joints of the foot and ankle. Discussion of the effects of an external ankle-support system necessitates a review of the normal biomechanical function of the foot and ankle, and clear distinctions need to be made among various terms used to describe foot and ankle motion.[101,102]

PATHOMECHANICAL CONSIDERATIONS

Many authors and clinicians use the coupled terms *eversion-inversion* to define motion confined to the frontal plane, and the coupled terms *pronation-supination* to define triplanar motion that occurs around the functional axis of the subtalar joint. Others make the distinction between uniplanar and triplanar motion in an opposite manner, and some use the 2 sets of terms interchangeably. Further complicating the matter, pronation-supination is commonly used to describe triplanar displacement associated with normal gait, and eversion-inversion is commonly used to describe triplanar displacement associated with ankle-injury mechanisms. Regardless of whether the research methods employed to study the effects of ankle support have analyzed isolated frontal-plane motion or triplanar motion, researchers have almost exclusively used the term *inversion* to define either type of inward displacement of the plantar aspect of the foot. Because this discussion relates to the pathomechanics of ankle injury, the terms *frontal-plane inversion* and *subtalar inversion* will be used to differentiate the uniplanar component of the injury-producing motion from the more complex triplanar motion that occurs between the leg and the foot.

INVERSION-EVERSION MECHANICS

The talus is the key structure of the ankle, linking the leg and the foot in a manner similar to a universal joint.[103] The leg is hinged to the talus in 1 plane at the talocrural joint; the foot is hinged to the talus in a different plane at the subtalar joint. The function of the subtalar joint is highly integrated with that of the talocrural joint proximally, as well as that of the tranverse tarsal and lateral tarsometatarsal joints distally. The configuration of the articular surfaces between the talus and the calcaneus is the primary determinant of the pattern of foot displacement that results from subtalar motion. Because the functional axis of the subtalar joint approximates a 45° orientation in relation to the long axis of the foot in the sagittal plane (Figure 1), it has been compared with a mitered hinge that produces opposite and equal amounts of rotation of the proximal and distal hinged segments.[104] Under weight-bearing conditions, the coupling mechanism created by the integrated function of the talocrural, subtalar, and transverse tarsal joints acts like a torque converter between the leg and the foot. Rotation of either segment is associated with rotation of the other segment in the opposite direction. The relative amounts of foot displacement and axial leg rotation associated with subtalar motion vary considerably among individuals and are related to the structure, alignment, and ligamentous integrity of the ankle and foot joints.[105]

Although subtalar inversion causes the talus to rotate exter-

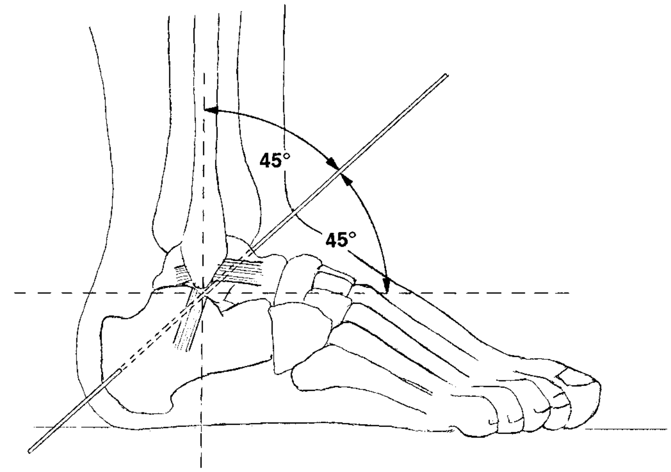

Figure 1. Approximate orientation of functional axis of the subtalar joint in the sagittal plane for most individuals.

nally with respect to the calcaneus in the transverse plane, the transfer of inversion torque between the talocrural joint and the lower leg is associated with external rotation of the lower leg in relation to the talus after the subtalar joint has reached the limit of its range of motion. If the lateral border of the foot inverts, the lateral tarsometatarsal joints, the transverse tarsal joint, and the subtalar joint each lock when the maximum range of inversion is reached, and the entire foot acts as a rigid lever that rotates inwardly around the subtalar axis while the lower leg rotates externally (Figure 2). If the anterior talofibular ligament (ATFL) is disrupted, the composite axis of talocrural-subtalar motion is no longer fixed, and the anterolateral portion of the talus is free to rotate out from beneath the tibiofibular mortise.[103,106–113] The term *anterolateral rotary instability* refers to anterior and internal rotary displacement of the lateral border of the talus in relation to the lower leg.[109,113–115]

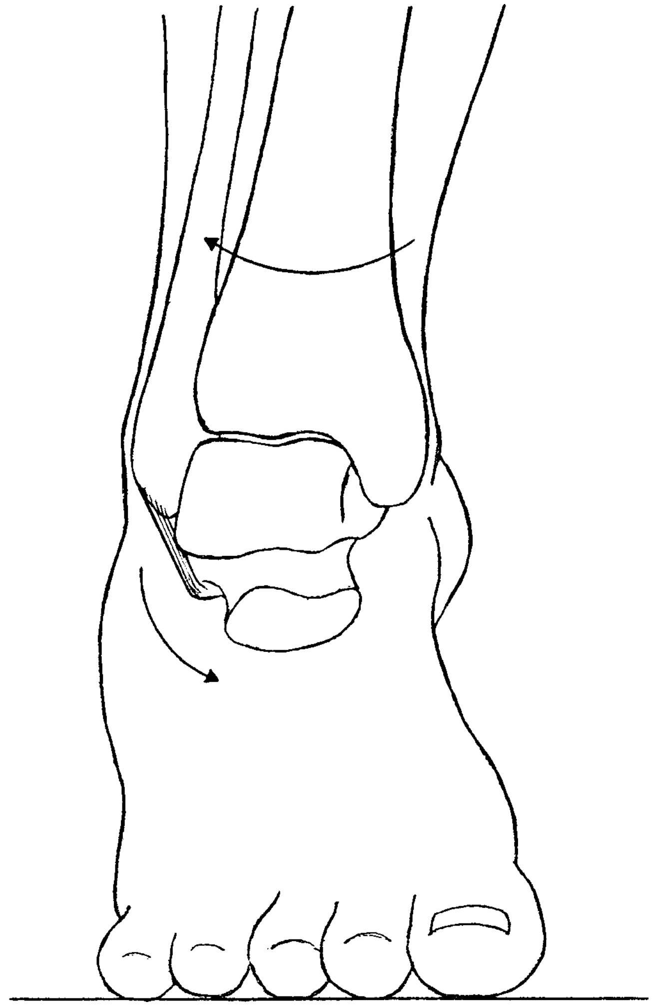

Figure 2. Development of tension within the anterior talofibular ligament as the leg externally rotates in relation to the foot, which resists rotary subluxation of the talus.

CLINICAL EVALUATION AND MANAGEMENT OF ANKLE INSTABILITY

To evaluate the integrity of the ATFL, stress radiography has been used to quantify anterior translation of the talus in relation to the calcaneus within the sagittal plane and varus tilt of the talus in relation to the tibia within the frontal plane. The lack of a consistent relationship between radiographic evidence of talocrural joint instability and symptoms of chronic ankle dysfunction after an inversion sprain is largely responsible for widespread acceptance of the idea that mechanical instability and functional instability are distinctly different conditions. Many believe that a deficiency in joint proprioception is responsible for symptoms of functional instability in the absence of mechanical instability, but some authors have suggested that traditional methods of clinical evaluation are inadequate for identification of rotary mechanical instability within the transverse plane.[103,106,110,111,113,115]

Because severe damage to the lateral ankle ligaments has been associated with increased talar tilt, prevention of frontal-plane displacement of the calcaneus and talus has been a primary goal guiding the design of ankle-support systems. The notion that talar tilt is the primary component of the mechanism responsible for disruption of the lateral ankle ligaments is refuted by research findings derived from axially loaded cadaver specimens. Cass and Settles[106] found that isolated release of the ATFL was not associated with talar tilt when an axial load was applied to an inverted hindfoot. Unlike other cadaver studies of pathologic ankle displacement, axial rotation of the leg was not constrained. These researchers[106] and others[101,110–113,116–118] have emphasized the role of the ATFL in restraining external rotation of the leg upon the talus. Much of the research that has evaluated the mechanical effects of ankle support has involved assessment of isolated frontal-plane motion of the foot in relation to the leg, and no study has assessed the effect of ankle taping or bracing on leg rotation.

In recent years, magnetic resonance imaging (MRI) has clearly demonstrated that ligamentous damage can be more severe than associated physical signs and symptoms might suggest.[119,120] Magnetic resonance imaging has also dramatically increased awareness of various types of soft tissue conditions that were previously unrecognized. Frey et al[120] compared ankle-sprain severity diagnoses made by orthopaedic surgeons with MRI results and concluded that clinicians often underestimate the severity of ligamentous damage in the absence of a complete ligament rupture. Several recent reports have emphasized MRI evidence that the ligaments of the subtalar joint are frequently damaged in patients who experience chronic ankle dysfunction after an inversion sprain.[120–122]

Hertel et al[123] used stress fluoroscopy to demonstrate subtalar instability in 75% of subjects with a history of lateral ankle sprain and evidence of talocrural instability (6 of 8 subjects). Tochigi et al[122] found MRI evidence of an ATFL lesion in all but 1 of 24 subjects diagnosed as having sustained either a moderate or severe inversion sprain, and more than 50% (13 of 24 subjects) had an interosseus talocalcaneal ligament lesion in the subtalar joint. Other lesions associated with a history of inversion ankle sprain that are extremely difficult to diagnose without MRI affect the calcaneofibular ligament, the cervical ligament, the lateral talocalcaneal ligament, the posterior talofibular ligament, the deltoid ligament, the peroneus longus tendon, the peroneus brevis tendon, the posterior tibialis tendon, the inferior peroneal retinaculum, and the lateral root of the inferior extensor retinaculum.[119,120,122–124]

A strong probability exists that chronic ankle dysfunction is related to inadequate treatment of rotational instability of the talocrural joint or undiagnosed abnormality of the subtalar joint.[103,106,110,114,119–123] Johnson and Markolf[111] observed that sectioning of the ATFL in cadaver specimens produced a surprisingly low failure level for the remaining ligaments (3 Nm) and emphasized that an unprotected injured ankle is highly susceptible to further injury. Hertel et al[123] noted that little emphasis has been placed on specifically limiting subtalar motion with ankle braces. A taping procedure for stabilization of the subtalar joint, referred to as the subtalar sling, has previously been reported.[21,29,51] A similar technique of tape application, referred to as the inversion brake, was presented by Vaes et al.[59]

RATIONALE FOR SUBTALAR TAPING PROCEDURE

Although numerous combinations of tape-strip orientations and wrapping patterns have been advocated as superior ankle-taping procedures, the basic components of the application procedure described by Gibney[1] in 1895 are included in almost every contemporary ankle-taping procedure. The Gibney basketweave procedure consists of an interwoven application of stirrup strips, which cover the plantar surface of the hindfoot and extend proximally on both the medial and lateral aspects of the leg, and horseshoe strips, which are applied perpendicular to the stirrup strips on the hindfoot.[29,31] Most athletic trainers use an ankle-taping procedure that incorporates some variation of the Gibney basketweave in combination with the Louisiana heel-lock and figure-8 wrapping patterns.

Although inward displacement of the hindfoot is generally associated with triplanar rotation around the functional axis of the subtalar joint, external forces can impose a nonfunctional rotation around the long axis of the foot when it is in a neutral or dorsiflexed position. The force vector created by tension within the longitudinal fibers of stirrup strips is perpendicular to an anteroposterior axis of isolated frontal-plane inversion when the talocrural joint is in a neutral position (Figure 3). Thus, stirrup strips are well positioned to provide maximum restraint to inward displacement of the hindfoot within the frontal plane (ie, varus displacement of the calcaneus and lateral tilting of the talus within the talocrural mortise). The application of heel-lock and figure-8 components further encases the hindfoot, which probably provides additional resistance to lateral distraction of the talocrural and subtalar joints within the frontal plane.

Because torque is transferred through the kinetic chain from the forefoot to the leg and vice versa, efforts to stabilize the talocrural joint should not be limited to restricting inward hindfoot motion within the frontal plane. The subtalar sling consists of 1 or more strips of high-strength, semielastic tape that spans all of the joints between the forefoot and leg (ie, tarsometatarsal, transverse tarsal, subtalar, and talocrural). The subtalar-sling component is applied after the stirrup and horseshoe strips and before the heel-lock configuration to the hindfoot and overlapping circumferential closure strips on the foot and leg. To resist subtalar inversion, the tape strips are anchored on the plantar aspect of the forefoot, wrapped around the lateral border of the foot, and wrapped around the leg above the malleoli. When viewed in the sagittal plane, the midportion subtalar sling has a 45° orientation that is approximately perpendicular to the orientation of the functional axis of the subtalar joint (Figure 4). The semielastic tape strips are applied with sufficient tension to create a lateral ‘‘bowstring effect’’ when anchored to the leg. Excessive tension may cause discomfort to develop along the lateral border of the foot during activity, whereas insufficient tension fails to restrict the end range of subtalar inversion after exercise-induced loosening. Nonelastic tape covers and secures the subtalar-sling attachment to the plantar aspect of the forefoot, and the lateral bowstringing portion is pulled against the surface of the midfoot through the application of a heel-lock tape configuration.

The incorporation of the lateral subtalar sling with other components of a traditional hindfoot-taping procedure increased residual subtalar inversion restriction after 2 to 3 hours of physical activity by 94% compared with the traditional procedure without the additional component.[21] Compared with the unrestricted range of inversion, the taping procedure that incorporated the lateral subtalar sling provided a residual restriction of 16.5° (41% of 40° unrestricted range), whereas the taping procedure without the subtalar sling provided a residual restriction of 8.5° (21% of 40° unrestricted range).

The vector created by tension within the lateral subtalar sling has a vertical component that resists varus displacement of the forefoot in the frontal plane and an anteroposterior component that resists anterior translation of the talus in the sagittal plane (Figure 5). Probably more important is its effect on torque transmission between the forefoot and leg and restraint of rotary subluxation of the talus in the transverse plane (Figure 6). External rotation of the leg increases tension within the

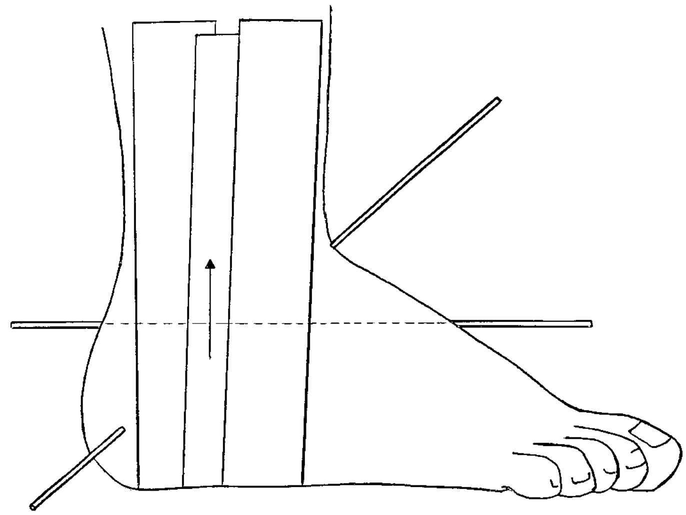

Figure 3. Vector created by tension within stirrup strips perpendicular to anteroposterior axis of isolated frontal-plane inversion.

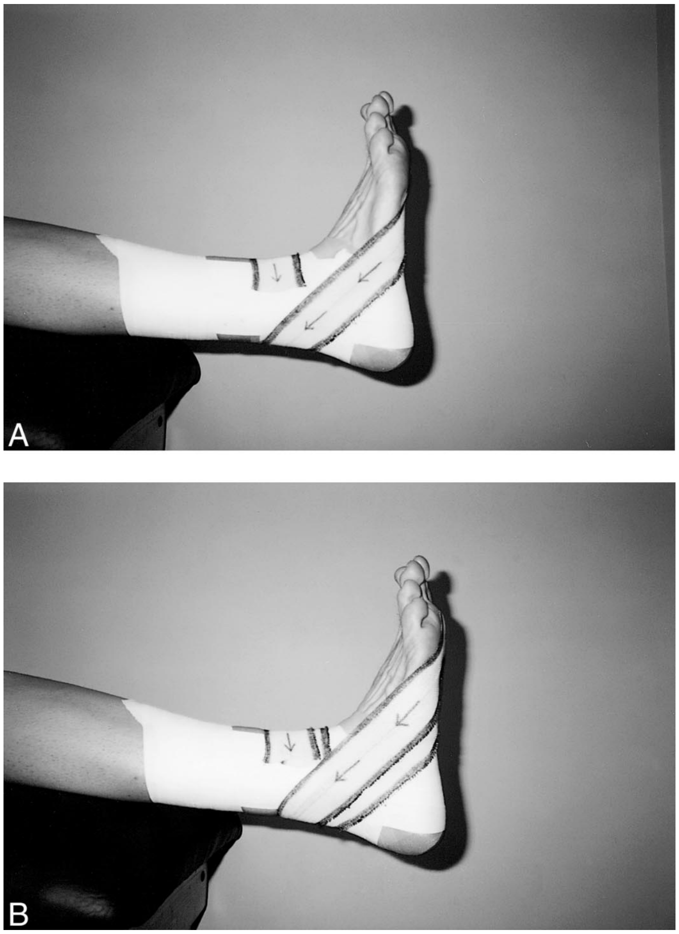

Figure 4. Lateral subtalar sling. A, Orientation of lateral subtalar sling applied over stirrup strips on the hindfoot. B, Optional second lateral subtalar sling wraps around the lateral aspect of the foot at a more distal position.

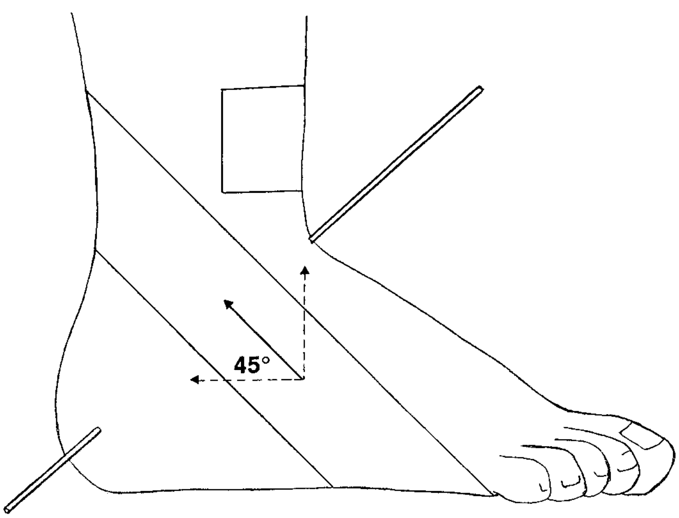

Figure 5. Vertical and anteroposterior components of the vector created by tension within the lateral subtalar sling.

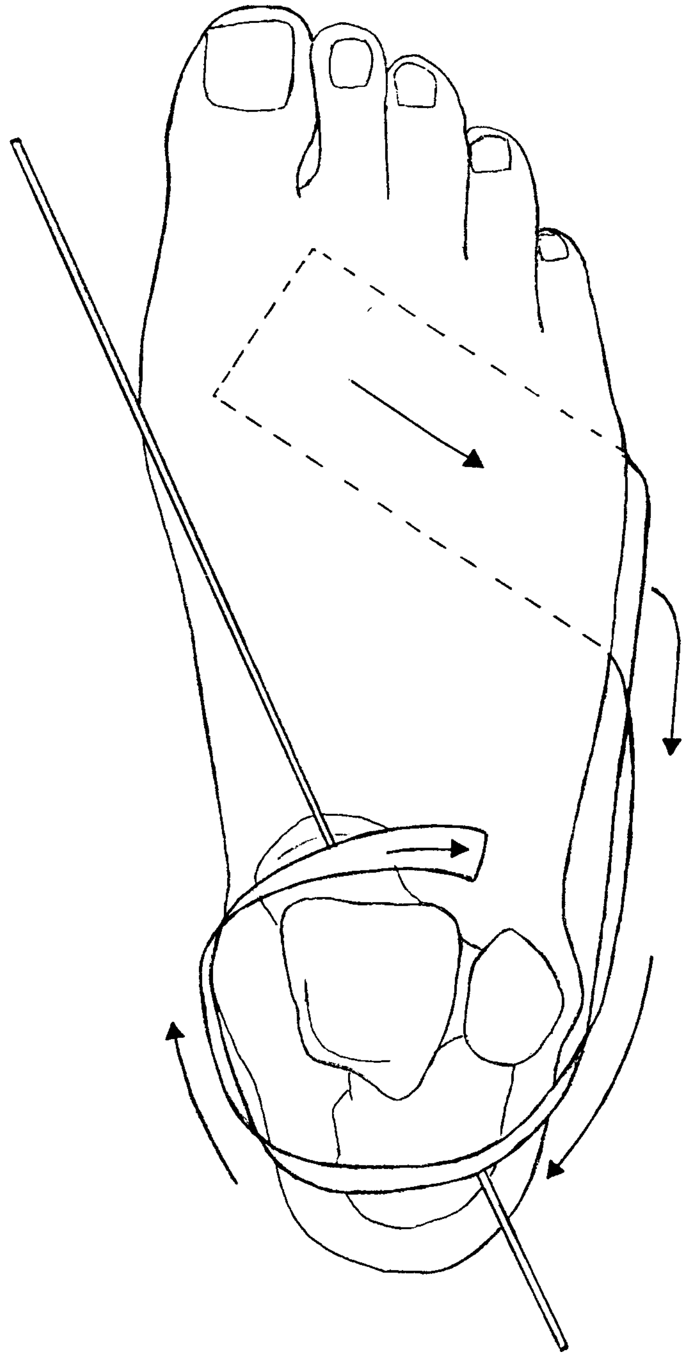

Figure 6. Restraint of anterolateral rotary subluxation of talus provided by the lateral subtalar sling as tape tension develops with external rotation of the leg.

tape strips forming the lateral subtalar sling, which tends to lift the lateral border of the foot, thereby reversing the normal effect of external leg rotation on the forefoot and protecting the ATFL from tensile loading.

The point at which the lateral subtalar sling wraps around the border of the foot affects the degree of discomfort experienced by some athletes and is a major factor determining the extent to which the sling achieves the desired effect. The more anterior on the foot the sling is applied, the longer the moment arm is between the functional axis of the subtalar joint and the sling fixation point on the lateral border of the foot. A more posterior position may be more comfortable for the athlete but lacks the mechanical advantage of the more anterior position (Figure 7). Although discomfort is sometimes experienced by athletes who are unaccustomed to the pressure exerted by the tape on the lateral border of the forefoot, those who complain

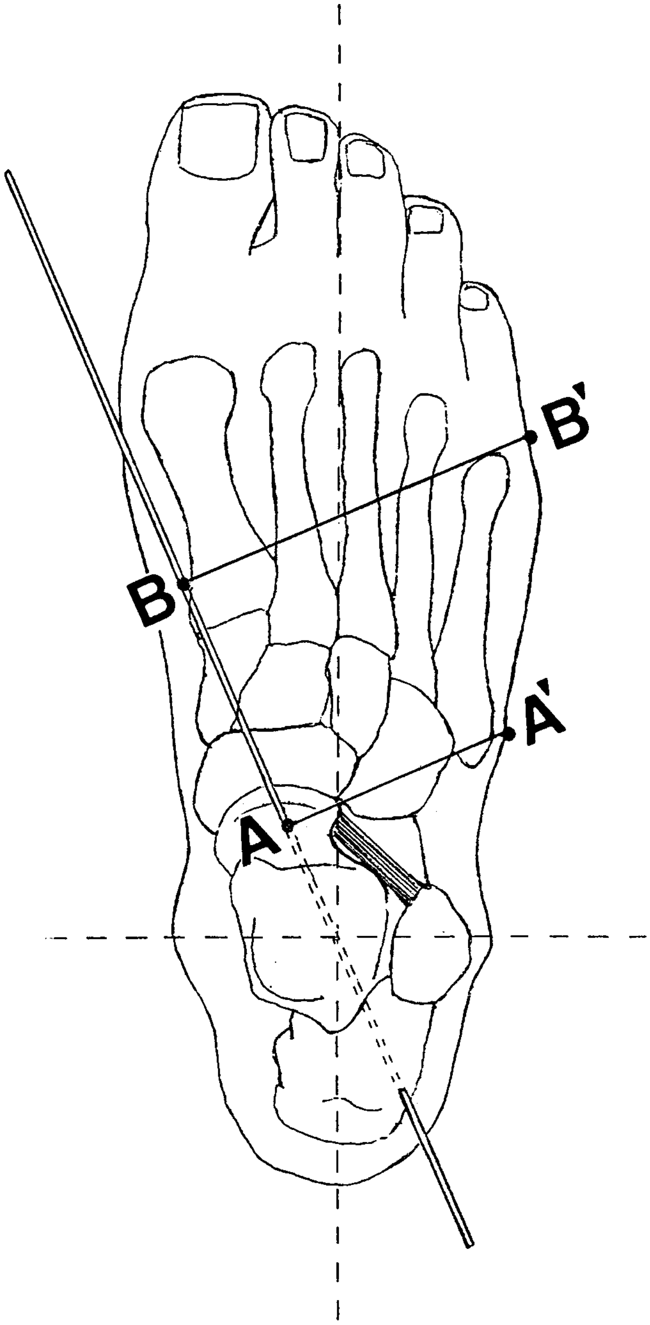

Figure 7. Comparison of moment arms resisting subtalar inversion associated with a more posterior lateral sling position (A-A′) versus a more anterior position (B-B′).

Figure 8. Medial subtalar sling applied over stirrup strips on hindfoot.

generally become more tolerant of the procedure after several applications.[51]

The subtalar sling can also be applied to the medial aspect of the foot to support the medial longitudinal arch and to control subtalar eversion (Figure 8). Although the mechanism is unclear, MRI evidence of damage to the deltoid ligament and the posterior tibialis tendon has been associated with a history of an inversion ankle sprain and concomitant damage to the lateral structures.[120,122] Several investigators have reported a relationship between lateral ankle-ligament injury and a deficiency in the isokinetic performance of the ankle invertors.[125–128] This phenomenon is believed to be caused by neural inhibition of the muscles that produce the motion associated with the injury mechanism,[129] and the degree of inhibition after an acute lateral sprain appears to be related to the amount of traumatic edema associated with the injury.[130] Stabilization of the talonavicular joint by the posterior tibialis muscle is essential for transfer of the force generated by the gastrocnemius-soleus muscles at their insertion on the calcaneus to the forefoot at push-off. Use of the medial subtalar sling may compensate for deficient posterior tibialis function, thereby facilitating the hindfoot-to-forefoot force transfer that occurs between the midstance and push-off phases of the gait cycle.

Another potentially important clinical application for the medial subtalar sling is the prevention of anterior-inferior tibiofibular syndesmosis sprain. The mechanism of injury associated with the syndesmotic ankle sprain involves external rotation of the foot and internal rotation of the lower leg.[131–134] Restriction of subtalar eversion, which is associated with foot and leg rotation in opposite directions, can reduce the amount of stress imposed on the syndesmosis by functional activities. Because susceptibility to an inversion sprain is always a concern, a taping procedure that incorporates the medial subtalar sling should always include application of the lateral subtalar sling.

CONCLUSIONS

Although the relative effectiveness of taping versus bracing for restraint of excessive inversion has not been clearly established, both types of ankle support clearly provide beneficial protective effects. During the acute phase of ankle-sprain management, bracing offers advantages related to ease of repetitive removal and reapplication, adjustability of strap or lace tension, and structural features that may facilitate edema resolution. Research findings suggest that taping may provide superior benefits with regard to deceleration of inversion velocity and facilitation of dynamic neuromuscular protective mechanisms. Furthermore, taping offers a means to address the complex interrelated biomechanical factors that are responsible for subtalar joint injury and rotary instability of the talocrural joint. Future research on the effectiveness of various braces and taping procedures should use methods that assess rotary displacements of both the foot and lower leg within the transverse plane.

REFERENCES

1. Gibney VP. Sprained ankle: a treatment that involves no loss of time, requires no crutches, and is not attended with an ultimate impairment of function. *NY Med J.* 1895;61:193–197.
2. Garrick JG, Requa RK. Role of external support in the prevention of ankle sprains. *Med Sci Sports.* 1973;5:200–203.
3. Alt W, Lohrer H, Gollhofer A. Functional properties of adhesive ankle taping: neuromuscular and mechanical effects before and after exercise. *Foot Ankle Int.* 1999;20:238–245.
4. Delacerda FG. Effect of underwrap conditions on the supportive effectiveness of ankle strapping with tape. *J Sports Med Phys Fitness.* 1978; 18:77–81.
5. Fumich RM, Ellison AE, Guerin GJ, Grace PD. The measured effect of taping on combined foot and ankle motion before and after exercise. *Am J Sports Med.* 1981;9:165–170.
6. Karlsson J, Andréasson GO. The effect of ankle support in chronic lateral ankle joint instability: an electromyographic study. *Am J Sports Med.* 1992;20:257–261.
7. Keetch AK, Johnson MB, Allsen PE, Durrant E. Effects of adhesive spray and prewrap on taped ankle inversion before and after exercise [abstract]. *J Athl Train.* 1992;27:152.
8. Larsen E. Taping the ankle for chronic instability. *Acta Orthop Scand.* 1984;55:551–553.
9. Laughman RK, Carr TA, Chao EY, Youdas JW, Sim FH. Three-dimensional kinematics of the taped ankle before and after exercise. *Am J Sports Med.* 1980;8:425–431.
10. Lohrer H, Alt W, Gollhofer A. Neuromuscular properties and functional aspects of taped ankles. *Am J Sports Med.* 1999;27:69–75.
11. Malina RM, Plagenz LB, Rarick GL. Effect of exercise upon the measurable supporting strength of cloth and tape wraps. *Res Q.* 1963;34: 158–165.
12. Manfroy PP, Ashton-Miller JA, Wojtys EM. The effect of exercise, prewrap, and athletic tape on the maximal active and passive ankle resistance of ankle inversion. *Am J Sports Med.* 1997;25:156–163.
13. Morris HH, Musnicki W III. The effect of taping on ankle mobility following moderate exercise. *J Sports Med Phys Fitness.* 1983;23:422–426.
14. Myburgh KH, Vaughan CL, Isaacs SK. The effects of ankle guards and taping on joint motion before, during, and after a squash match. *Am J Sports Med.* 1984;12:441–446.
15. Pederson TS, Ricard MD, Merrill G, Schulthies SS, Allsen PE. The effects of spatting and ankle taping on inversion before and after exercise. *J Athl Train.* 1997;32:29–33.
16. Pope MH, Renstrom P, Donnermeyer D, Morgenstern S. A comparison of ankle taping methods. *Med Sci Sports Exerc.* 1987;19:143–147.
17. Rarick GL, Bigley G, Karst R, Malina RM. The measurable support of the ankle joint by conventional methods of taping. *J Bone Joint Surg Am.* 1962;44:1183–1190.
18. Ricard MD, Sherwood SM, Schulthies SS, Knight KL. Effects of tape and exercise on dynamic ankle inversion. *J Athl Train.* 2000;35:31–37.
19. Seitz CJ, Goldfuss AJ. The effect of taping and exercise on passive foot inversion and ankle plantarflexion. *Athl Train J Natl Athl Train Assoc.* 1984;19:178–182.
20. Vaes P, De Boeck H, Handlberg F, Opdecam P. Comparative radiological study of the influence of ankle joint strapping and taping on ankle stability. *J Orthop Sports Phys Ther.* 1985;7:110–114.
21. Wilkerson GB. Comparative biomechanical effects of the standard method of ankle taping and a taping method designed to enhance subtalar stability. *Am J Sports Med.* 1991;19:588–595.
22. Arnheim DD. *Modern Principles of Athletic Training.* 7th ed. St Louis, MO: Times Mirror/Mosby; 1989:322–326.
23. Bilik SE. *The New Trainers Bible.* 6th ed. New York, NY: Atsco Press; 1934:84–90.
24. Bonci CM. Adhesive strapping techniques. *Clin Sports Med.* 1982;1:99–116.
25. Bullard RH, Dawson J, Arenson DJ. Taping the ‘‘athletic ankle.’’ *J Am Podiatr Assoc.* 1979;69:727–734.
26. Davies GJ. The ankle wrap: variation from the traditional. *Athl Train J Natl Athl Train Assoc.* 1977;12:194–197.
27. Felder CR, McNeeley J. Ankle taping: an alternative to the basketweave. *Athl Train J Natl Athl Train Assoc.* 1978;13:152–156.
28. Hinton SG. The Hinton-Boswell method of preventive ankle taping. *Athl Train J Natl Athl Train Assoc.* 1979;14:34–37.
29. Irvin R, Iverson D, Roy S. *Sports Medicine Prevention, Evaluation, Management, and Rehabilitation.* 2nd ed. Boston, MA: Allyn & Bacon; 1998:59–61.
30. Thornton JL, Webster JA. The ‘‘tape cast’’ functional taping for the injured athlete. *J Athl Train.* 1996;31:179–181.
31. Perrin DH. *Athletic Taping and Bracing.* Champaign, IL: Human Kinetics; 1995:18–24.
32. Emerick CE. Ankle taping: prevention of injury or waste of time? *Athl Train J Natl Athl Train Assoc.* 1979;14:149,150,188.
33. Ferguson AB Jr. The case against ankle taping. *J Sports Med.* 1973;1: 46–47.
34. Firer P. Effectiveness of taping for the prevention of ankle ligament sprains. *Br J Sports Med.* 1990;24:47–50.
35. Karlsson J, Swärd L, Andréasson GO. The effect of taping on ankle stability: practical implications. *Sports Med.* 1993;16:210–215.
36. MacCartee CC Jr. Taping treatment of severe inversion ankle sprains of the ankle: early return to functional activities. *Am J Sports Med.* 1977; 5:246–247.
37. Simon JE. Study of the comparative effectiveness of ankle taping and ankle wrapping on the prevention of ankle injuries. *Athl Train J Natl Athl Train Assoc.* 1969;4:6–7.
38. Thacker SB, Stroup DF, Branche CM, Gilchrist J, Goodman RA, Weitman EA. The prevention of ankle sprains in sports: a systematic review of the literature. *Am J Sports Med.* 1999;27:753–760.
39. Alves JW, Alday RV, Ketcham DL, Lentell GL. A comparison of the passive support provided by various ankle braces. *J Orthop Sports Phys Ther.* 1992;15:10–18.
40. Anderson DL, Sanderson DJ, Hennig EM. The role of external nonrigid ankle bracing in limiting ankle inversion. *Clin J Sport Med.* 1995;5:18–24.
41. Greene TA, Wight CR. A comparative support evaluation of three ankle orthoses before, during, and after exercise. *J Orthop Sports Phys Ther.* 1990;11:453–466.
42. Greene TA, Roland G. A comparative isokinetic evaluation of a functional ankle orthosis on talocalcaneal function. *J Orthop Sports Phys Ther.* 1989;11:245–252.
43. Gross MT, Ballard CL, Mears HC, Watkins EJ. Comparison of DonJoy Ankle Ligament Protector and Aircast Sport-Stirrup orthoses in restricting foot and ankle motion before and after exercise. *J Orthop Sports Phys Ther.* 1992;16:60–67.
44. Johnson RE, Veale JR, McCarthy GJ. Comparative study of ankle support devices. *J Am Podiatr Med Assoc.* 1994;84:107–114.
45. Kimura IF, Nawoczenski DA, Epler M, Owen MG. The effect of the AirStirrup in controlling inversion stress. *J Orthop Sports Phys Ther.* 1987;9:190–193.
46. Löfvenberg R, Kärrholm J. The influence of an ankle orthosis on the talar and calcaneal motions in chronic lateral instability of the ankle: a stereophotogrammetric analysis. *Am J Sports Med.* 1993;21:224–230.
47. Vaes PH, Duquet W, Casteleyn PP, Handelberg F, Opdecam P. Static and dynamic roentgenographic analysis of ankle stability in braced and nonbraced stable and functionally unstable ankles. *Am J Sports Med.* 1998; 26:692–702.
48. Ashton-Miller JA, Ottaviani RA, Hutchinson C, Wojtys EM. What best protects the inverted weightbearing ankle against further inversion? Evertor muscle strength compares favorably with shoe height, athletic tape, and three orthoses. *Am J Sports Med.* 1996;24:800–809.
49. Bunch RP, Bednarski K, Holland D, Macinanti R. Ankle joint support: a comparison of reusable lace-on braces with taping and wrapping. *Physician Sportsmed.* 1985;13(5):59–62.
50. Greene TA, Hillman SK. Comparison of support provided by a semirigid orthosis and adhesive ankle taping before, during, and after exercise. *Am J Sports Med.* 1990;18:498–506.
51. Gross MT, Batten AM, Lamm AL, et al. Comparison of DonJoy ankle ligament protector and subtalar sling ankle taping in restricting foot and

ankle motion before and after exercise. *J Orthop Sports Phys Ther.* 1994;19:33–41.
52. Gross MT, Lapp AK, Davis JM. Comparison of Swede-O Universal Ankle Support and Aircast Sport-Stirrup orthoses and ankle tape in restricting eversion-inversion before and after exercise. *J Orthop Sports Phys Ther.* 1991;13:11–19.
53. Gross MT, Bradshaw MK, Ventry LC, Weller KH. Comparison of support provided by ankle taping and semirigid orthosis. *J Orthop Sports Phys Ther.* 1987;9:33–39.
54. Hughes LY, Stetts DM. A comparison of ankle taping and a semirigid support. *Physician Sportsmed.* 1983;11(4):99–103.
55. Martin N, Harter RA. Comparison of inversion restraint provided by ankle prophylactic devices before and after exercise. *J Athl Train.* 1993; 28:324–329.
56. Metcalfe RC, Schlabach GA, Looney MA, Renehan EJ. A comparison of moleskin tape, linen tape, and lace-up brace on joint restriction and movement performance. *J Athl Train.* 1997;32:136–140.
57. Paris DL, Vardaxis V, Kokkaliaris J. Ankle ranges of motion during extended activity periods while taped and braced. *J Athl Train.* 1995; 30:223–228.
58. Shapiro MS, Kabo JM, Mitchell PW, Loren G, Tsenter M. Ankle sprain prophylaxis: an analysis of the stabilizing effects of braces and tape. *Am J Sports Med.* 1994;22:78–82.
59. Vaes PH, Duquet W, Handelberg F, Casteleyn PP, Tiggelen RV, Opdecam P. Influence of ankle strapping, taping, and nine braces: a stress roentgenologic comparison. *J Sport Rehabil.* 1998;7:157–171.
60. Cordova ML, Ingersoll CD, LeBlanc MJ. Influence of support on joint range of motion before and after exercise: a meta-analysis. *J Orthop Sports Phys Ther.* 2000;30:170–182.
61. Sitler MR, Ryan J, Wheeler B, et al. The efficacy of a semirigid ankle stabilizer to reduce acute ankle injuries in basketball: a randomized clinical study at West Point. *Am J Sports Med.* 1994;22:454–461.
62. Surve I, Schwellnus MP, Noakes T, Lombard C. A fivefold reduction in the incidence of recurrent ankle sprains in soccer players using the Sport-Stirrup orthosis. *Am J Sports Med.* 1994;22:601–606.
63. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med.* 1985;13:259–262.
64. Rovere GD, Clarke TJ, Yates CS, Burley K. Retrospective comparison of taping and ankle stabilizers in preventing ankle injuries. *Am J Sports Med.* 1988;16:228–233.
65. Sharpe SR, Knapik J, Jones B. Ankle braces effectively reduce recurrence of ankle sprains in female soccer players. *J Athl Train.* 1997;32: 21–24.
66. Abdenour TE, Saville WA, White RC, Abdenour MA. The effect of ankle taping upon torque and range of motion. *Athl Train J Natl Athl Train Assoc.* 1979;14:227–228.
67. Beriau MR, Cox WB, Manning J. Effects of ankle braces upon agility course performance in high school athletes. *J Athl Train.* 1994;29:224–230.
68. Bocchinfuso C, Sitler MR, Kimura I. Effects of two semirigid prophylactic ankle stabilizers on performance involving speed, agility, and vertical jump. *J Sport Rehabil.* 1994;3:125–134.
69. Burks RT, Bean BG, Marcus R, Barker HB. Analysis of athletic performance with prophylactic ankle devices. *Am J Sports Med.* 1991;19:104–106.
70. De Clercq DL. Ankle bracing in running: the effect of a Push type medium ankle brace upon movement of the foot and ankle during the stance phase. *Int J Sports Med.* 1997;18:222–228.
71. Feuerbach JW, Grabiner MD. Effect of the Aircast on unilateral postural control: amplitude and frequency variables. *J Orthop Sports Phys Ther.* 1993;7:149–154.
72. Fridén T, Zätterström R, Lindstrand A, Moritz U. A stabilometric technique for evaluation of lower limb instabilities. *Am J Sports Med.* 1989; 17:118–122.
73. Gehlsen GM, Pearson D, Bahamonde R. Ankle joint strength, total work, and ROM: comparison between prophylactic devices. *Athl Train J Natl Athl Train Assoc.* 1991;26:62–65.
74. Gross MT, Clemence LM, Cox BD, et al. Effect of ankle orthoses on functional performance for individuals with recurrent lateral ankle sprains. *J Orthop Sports Phys Ther.* 1997;25:245–252.
75. Gross MT, Everts JR, Roberson SE, Roskin DS, Young KD. Effect of DonJoy Ankle Ligament Protector and Aircast Sport-Stirrup Orthoses on functional performance. *J Orthop Sports Phys Ther.* 1994;19:150–156.
76. Hals TMV, Sitler MR, Mattacola CG. Effect of a semi-rigid ankle stabilizer on performance in persons with functional ankle instability. *J Orthop Sports Phys Ther.* 2000;30:552–556.
77. Juvenal JP. The effects of ankle taping on vertical jumping ability. *Athl Train J Natl Athl Train Assoc.* 1972;7:146–149.
78. Kozar B. Effects of ankle taping upon dynamic balance. *Athl Train J Natl Athl Train Assoc.* 1974;9:94–96.
79. Lindley TR, Kernozek TW. Taping and semirigid bracing may not affect ankle functional range of motion. *J Athl Train.* 1995:30:109–112.
80. Locke A, Sitler MR, Aland C, Kimura I. Long-term use of a softshell prophylactic ankle stabilizer on speed, agility, and vertical jump performance. *J Sport Rehabil.* 1997;6:235–245.
81. Macpherson K, Sitler MR, Kimura I, Horodyski M. Effects of a semirigid and softshell prophylactic ankle stabilizer on selected performance tests among high school football players. *J Orthop Sports Phys Ther.* 1995;21:147–152.
82. Mayhew JL. Effects of ankle taping on motor performance. *Athl Train J Natl Athl Train Assoc.* 1972;7:10–11.
83. Paris DL. The effects of the Swede-O, New Cross, and McDavid ankle braces and adhesive ankle taping on speed, balance, agility, and vertical jump. *J Athl Train.* 1992;27:253–256.
84. Pienkowski D, McMorrow M, Shapiro R, Caborn D, Stayton J. The effect of ankle stabilizers on athletic performance: a randomized prospective study. *Am J Sports Med.* 1995;23:757–762.
85. Verbrugge JD. The effects of semirigid Air-Stirrup bracing vs. adhesive taping on motor performance. *J Orthop Sports Phys Ther.* 1996;23:320–325.
86. Eiff MP, Smith AT, Smith GE. Early mobilization versus immobilization in the treatment of lateral ankle sprains. *Am J Sports Med.* 1994;22:83–88.
87. Kannus P, Renström P. Treatment for acute tears of the lateral ligaments of the ankle: operation, cast, or early controlled mobilization. *J Bone Joint Surg Am.* 1991;73:305–312.
88. Konradsen L, Hølmer P, Søndergaard L. Early mobilizing treatment for grade III ankle ligament injuries. *Foot Ankle.* 1991;12:69–73.
89. Stover CN. Air stirrup management of ankle injuries in the athlete. *Am J Sports Med.* 1980;8:360–365.
90. Stover CN. A functional semirigid support system for ankle injuries. *Physician Sportsmed.* 1979;7(5):71–78.
91. Guskiewicz KM, Riemann BL, Onate JA. Comparison of 3 methods of external support for management of acute lateral ankle sprains. *J Athl Train.* 1999;34:5–10.
92. Wilkerson GB, Horn-Kingery HM. Treatment of the inversion ankle sprain: comparison of different modes of compression and cryotherapy. *J Orthop Sports Phys Ther.* 1993;17:240–246.
93. Feuerbach JW, Grabiner MD, Koh TJ, Weiker GG. Effect of an ankle orthosis and ankle ligament anesthesia on ankle joint proprioception. *Am J Sports Med.* 1994;22:223–229.
94. Heit EJ, Lephart SM, Rozzi SL. The effect of ankle bracing and taping on joint position senses in the stable ankle. *J Sport Rehabil.* 1996;5: 206–213.
95. Simoneau GG, Degner RM, Kramper CA, Kittelson KH. Changes in ankle joint proprioception resulting from strips of athletic tape applied over the skin. *J Athl Train.* 1997;32:141–147.
96. Glick JM, Gordon RB, Nishimoto D. The prevention and treatment of ankle injuries. *Am J Sports Med.* 1976;4:136–141.
97. Sprigings EJ, Pelton JD, Brandell BR. An EMG analysis of the effectiveness of external ankle support during sudden ankle inversion. *Can J Appl Sports Sci.* 1981;6:72–75.
98. Clarke TE, Frederick EC, Hamill CL. The effects of shoe design parameters on rearfoot control in running. *Med Sci Sports Exerc.* 1983;15: 376–381.
99. Ricard MD, Saret JJ, Schulthies SS. Comparison of the amount and rate

of inversion between high top and low top shoes [abstract]. *J Athl Train.* 1997;32(suppl):S-13.
100. Konradsen L, Voigt M, Højsgaard C. Ankle inversion injuries: the role of the dynamic defense mechanism. *Am J Sports Med.* 1997;25:54–58.
101. Renstrom P, Wertz M, Incavo S, et al. Strain in the lateral ligaments of the ankle. *Foot Ankle.* 1988;9:59–63.
102. Rockar PA Jr. The subtalar joint: anatomy and joint motion. *J Orthop Sports Phys Ther.* 1995;21:361–372.
103. Conlin FD, Johnson PG, Sinning JE Jr. The etiology and repair of rotary ankle instability. *Foot Ankle.* 1989;10:152–155.
104. Inman VT. *The Joints of the Ankle.* Baltimore, MD: Williams & Wilkins; 1976:35–43.
105. Nawoczenski DA, Saltzman CL, Cook TM. The effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. *Phys Ther.* 1998;78:404–416.
106. Cass JR, Settles H. Ankle instability: in vitro kinematics in response to axial load. *Foot Ankle Int.* 1994;15:134–140.
107. Cass JR, Morrey BF, Chao EY. Three dimensional kinematics of ankle instability following serial sectioning of the lateral collateral ligaments. *Foot Ankle.* 1984;5:142–149.
108. Cass JR, Morrey BF. Ankle instability: current concepts, diagnosis, and treatment. *Mayo Clin Proc.* 1984;59:165–170.
109. Cotler JM. Lateral ligamentous injuries of the ankle. In: Hamilton WC, ed. *Traumatic Disorders of the Ankle.* New York, NY: Springer-Verlag; 1984:113–123.
110. Hintermann B. Biomechanics of the unstable ankle joint and clinical implications. *Med Sci Sports Exerc.* 1999;31(7 suppl):459–469.
111. Johnson EE, Markolf KL. The contribution of the anterior talofibular ligament to ankle laxity. *J Bone Joint Surg Am.* 1983;65:81–88.
112. Parlasca R, Shoji H, D'Ambrosia RD. Effects of ligamentous injury on ankle and subtalar joints: a kinematic study. *Clin Orthop.* 1979;140:266–272.
113. Rasmussen O, Tovborg-Jensen I. Anterolateral rotational instability in the ankle joint: an experimental study of anterolateral rotational instability, talar tilt, and anterior drawer sign in relation to injuries to the lateral ligaments. *Acta Orthop Scand.* 1981;52:99–102.
114. Thermann H, Zwipp H, Tscherne H. Treatment algorithm of chronic ankle and subtalar instability. *Foot Ankle Int.* 1997;18:163–169.
115. Wilkerson GB, Nitz AJ. Dynamic ankle stability: mechanical and neuromuscular interrelationships. *J Sport Rehabil.* 1994;3:43–57.
116. Colville MR, Marder RA, Boyle JJ, Zarins B. Strain measurements in lateral ankle ligaments. *Am J Sports Med.* 1990;18:196–200.
117. McCullough CJ, Burge PD. Rotary stability of the load-bearing ankle. *J Bone Joint Surg Br.* 1980;62:460–464.
118. Stormont DM, Morrey BF, An KN, Cass JR. Stability of the loaded ankle: relation between articular restraint and primary and secondary static restraints. *Am J Sports Med.* 1985;13:295–300.
119. Oloff LM, Sullivan BT, Heard GS, Thornton MC. Magnetic reasonance imaging of traumatized ligaments of the ankle. *J Am Podiatr Med Assoc.* 1992;82:25–32.
120. Frey C, Bell J, Teresi L, Kerr R, Feder K. A comparison of MRI and clinical examination of acute lateral ankle sprains. *Foot Ankle Int.* 1996; 17:533–537.
121. Pisani G. Chronic laxity of the subtalar joint. *Orthopedics.* 1996;19:431–437.
122. Tochigi Y, Yoshinaga K, Wada Y, Moriya H. Acute inversion injury of the ankle: magnetic reasonance imaging and clinical outcomes. *Foot Ankle Int.* 1998;19:730–734.
123. Hertel J, Denegar CR, Monroe MM, Stokes WL. Talocrural and subtalar joint instability after lateral ankle sprain. *Med Sci Sports Exerc.* 1999; 31:1501–1508.
124. Stephens MM, Sammarco GJ. The stabilizing role of the lateral ligament complex around the ankle and subtalar joints. *Foot Ankle.* 1992;13:130–136.
125. Baumhauer JF, Alosa DM, Renström PA, Trevino S, Beynnon B. A prospective study of ankle injury risk factors. *Am J Sports Med.* 1995; 23:564–570.
126. Bernier JN, Perrin DH, Rijke A. Effect of unilateral functional instability of the ankle on postural sway and inversion and eversion strength. *J Athl Train.* 1997;32:226–232.
127. Ryan L. Mechanical stability, muscle strength, and proprioception in the functionally unstable ankle. *Aust J Physiother.* 1994;40:41–47.
128. Wilkerson GB, Pinerola JJ, Caturano RW. Invertor vs. evertor peak torque and power deficiencies associated with lateral ankle ligament injury. *J Orthop Sports Phys Ther.* 1997;26:78–86.
129. Swearingen RL, Dehne E. A study of pathological muscle function following injury to a joint [abstract]. *J Bone Joint Surg Am.* 1964;46:1364.
130. Hall RC, Nyland J, Nitz AJ, Pinerola J, Johnson DL. Relationship between ankle invertor H-reflexes and acute swelling induced by inversion ankle sprain. *J Orthop Sports Phys Ther.* 1999;29:339–344.
131. Boytim MJ, Fischer DA, Neumann L. Syndesmotic ankle sprains. *Am J Sports Med.* 1991;19:294–298.
132. Briner WW Jr, Carr DE, Lavery KM. Anteroinferior tibiofibular ligament injury: not just another ankle sprain. *Physician Sportsmed.* 1989; 17(11):63–69.
133. Brosky R, Nyland J, Nitz A, Caborn DN. The ankle ligaments: consideration of syndesmotic injury and implications for rehabilitation. *J Orthop Sports Phys Ther.* 1995;21:197–205.
134. Hopkinson WJ, St Pierre P, Ryan JB, Wheeler JH. Syndesmosis sprains of the ankle. *Foot Ankle.* 1990;10:325–330.